Short Course on Experimental Dynamic Substructuring

Module #09b: Fixed base constraints – another application

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Short Course Notes For:
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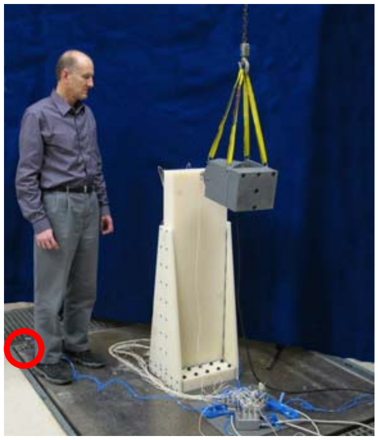
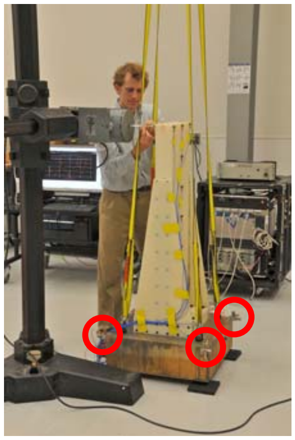
Slip Table Modal Test

- We desired to find the fixed base modes of a 72kg nylon beam mounted on a magnesium slip table with oil film riding on a granite block
- We performed a modal test with a 1125 N shaker and force gage and instrumented the slip table with 7 triaxial accelerometers which would later be constrained to achieve fixed base results
- We also needed a "truth test" to compare the fixed base modes against

Truth Test Hardware – Big mass for modes up to 250 Hz and smaller seismic mass for modes from 250-1380 Hz



Large Seismic Mass Test



Small Seismic Mass Test

Theory to Constrain Base Fixture Motion

Equations of Motion from modal test modes

$$\left[\backslash \omega_{n}^{2} \backslash \right]\{q\} - \omega^{2}[I]\{q\} = \Psi^{T}\{f\}$$

Constraint at all Fixture DoF Measurement Points

$$\{x_c\} = \{0\}$$

$$\Psi_c\{q\} = \{0\}$$

$$\Phi_c^{+}\Psi_c\{q\} = \{0\}$$

$$\Phi_c^{+}\Psi_c\mathbf{L}\{q_{new}\} = \{0\}$$

Substitute $\mathbf{L}$ and q_{new} into equations of motion, Premultiply by $\mathbf{L}^T$

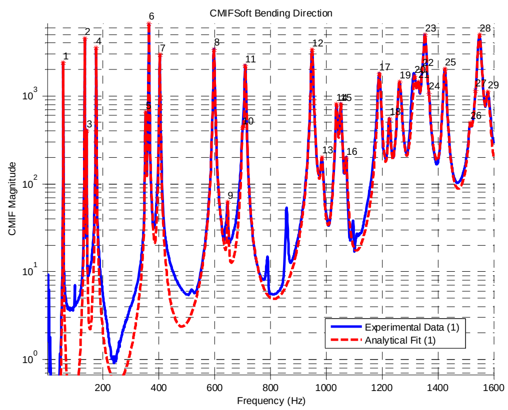
$$\mathbf{L}^T\left[\backslash \omega_{n}^{2} \backslash \right]\mathbf{L}\{q_{new}\} - \omega^{2}\mathbf{L}^T[I]\mathbf{L}\{q_{new}\} = \mathbf{L}^T\Psi^{T}\{f\}$$

Truth Test Results

- In both tests on seismic masses we tested with three orthogonal shakers with burst random to improve damping estimates
- Φ_c was calculated from just the six rigid body modes on the large seismic mass with four triaxes on each corner of the mass
- Φ_c was calculated from the six rigid body modes and first elastic bending mode (1380) Hz on the small seismic mass

Modal Test Results – Small Seismic Mass

- CMIFs (blue) for soft bending direction shown below with analytical CMIFs (red) generated from extracted modal parameters



Truth Test Results (Results in Green)

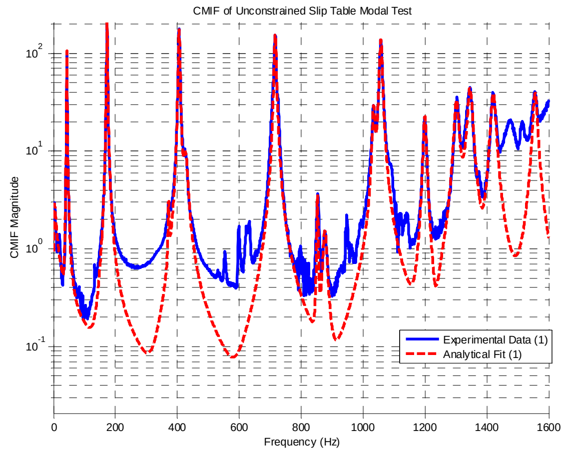
Description	Unconstrained Small Seismic Mass		Constrained Small Seismic Mass		Constrained Large Seismic Mass	
	Frequency	Damping	Frequency	Damping	Frequency	Damping
1st bend soft direction	57.85Hz	0.18%	38.99Hz	0.16%	38.54Hz	0.22%
1st bend stiff direction	135.18	0.21	89.05	0.18	91.13	0.19
1st torsion	142	0.25	134.31	0.21	134.0	0.20
2nd bend soft direction	175.75	0.24	163.61	0.22	164.0	0.24
2nd bend stiff direction	353.18	0.33	338.16	0.32	342.3	0.25
2nd torsion	364.91	0.26	364.24	0.26		
1st Axial	409.31	0.26	392.4	0.25		
3rd bend soft direction	403.90	0.32	396.4	0.31	394.8	0.32
3rd torsion	598.1	0.42	597.6	0.42		
3rd bend stiff	647.3	0.61	643.8	0.61		
4th torsion	700.5	0.47	700.4	0.47		
4th bend soft	710.4	0.37	706.4	0.37		
4th bend stiff	791.6	0.51	790.4	0.51		
5th bend soft	859.2	0.29	859.2	0.29		
5th torsion	949.5	0.41	949.2	0.41		
6th torsion	984.5	0.51	984.3	0.51		
6th bend soft	1037	0.43	1034.8	0.43		
7th bend soft	1052.5	0.43	1048.2	0.43		
2nd axial	1073	0.40	1062.3	0.39		
5th bend stiff	1099.6	0.39	1097.2	0.39		
8th bend soft	1190.7	0.49	1190.7	0.49		
7th torsion	1262.7	0.60	1263.1	0.60		
9th bend soft	1316.6	0.54	1316.1	0.54		
8th torsion	1330	0.45	1330.7	0.45		
10th bend soft	1344.3	0.51	1344.3	0.51		
11th bend soft	1354	0.47	1352.3	0.47		

Slip Table Modal Test

- Random excitation of 392 N RMS to 1600 Hz with Hann window
- SMAC modal analysis algorithm
- Φ_c to fix base had 1 rigid, 1 elastic mode (~2300 Hz)

Reconstructed CMIF from Slip Table Modal Test

CMIF from test data (blue) and synthesized from modal parameters (red)



Slip Table Modal Parameters

Description	Unconstrained Slip Table		Constrained to Fixed Base	
	Frequency	Damping	Frequency	Damping
1st bend soft direction	43.21 Hz	2.07%	38.19Hz	0.95%
2nd bend soft direction	173.09	0.86	162.27	0.73

Final Fixed Base Comparisons

Frequency-Hz	Truth Frequency	Est Frequency/Error	Truth Damping	Est Damping/Error
1st bend soft direction	38.54Hz	38.19Hz / -0.9%	0.22%	0.95% / 332%
2nd bend soft direction	164	162.27 / -1.1	0.24	0.73 / 204
3rd bend soft direction	396.4	393.03 / -0.9	0.31	0.60 / 94
4th bend soft	706.4	702.5 / -0.6	0.37	0.49 / 32
5th bend soft	859.2	852.9 / -0.7	0.29	0.25 / 14
6th bend soft	1034.8	1029.3 / -0.5	0.43	0.43 / 0
7th bend soft	1048.2	1041.5 / -0.6	0.43	0.44 / 2
8th bend soft	1190.7	1199.5 / 0.7	0.49	0.44 / -10
9th bend soft	1316.1	1301.5 / -1.1	0.54	0.60 / 11
10th bend soft	1344.3	1344.2 / -0.07	0.51	0.62 / 22

- 10 estimated fixed base frequencies for bending modes in direction of excitation within 1.1% of “Truth” values
- Damping errors are very large for lower modes, even with a correction for the viscous damping of the slip table

Comparison to calibrated FE model (Salinas)

- FE Model modulus of elasticity was calibrated to best fit of truth test fixed base frequencies.
- FE model was then within one percent of the truth test frequencies
- MAC values of FE model with test fixed base modes in soft direction were 1,1,.97,.95,.99,.91,.98,.95,.93,.78
- Note that there is another example of fixed base substructuring using FRFs from IMAC 28 in 2010, paper 236 by Mayes, Bitsie, Bridgers